Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2018, 5(4):252-267**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Mathematical Modelling of Wave Loads on Offshore Jacket for Shallow Water Applications

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Abstract Wave loads on offshore structures are inherent and are among the most severe hazard that it suffers. Sea information as well as data collection/collation and type of operation should be based on interest. The reliability, sustainability and performance of offshore jacket structures solely depend upon a good judgemental and experimental approach to truly determine the applied loads that make the structures behave the way they do in their offshore environment. Hence the amount of defect meted on the structure is modelled. Wave loads derivative that characterised forces on the vertical piles of the structures are computed using MATLAB programming language. The incident wave angle was taken from 0^0 to 360^0 to make a period at 15^0 intervals. The mathematical modelling derived was critically applied to ascertain the integrity of offshore jacket maintaining the linear approach. An investigation has equally been performed, forces analysed revealed that wave loads are the major threats facing the structure hence modelling achieves a great deal of result which shows that the maximum average force it can carry is 146.15kN, anything more than this the structure may experience buckling. The different in forces calculated validated the linear method to be conservative since no significant different between the total force and the total moment was observed. The moment acting on the jacket for different wave incident angles revealed that, by choosing the maximum moment generating load enhances the stability of the structure. Also, marine growths and fouling increase failure rapidly on a fixed jacket facilitating a progressive failure in the structural response in shallow water. Furthermore, it was observed that the vertical stress is proportional to the depth of the water. More diagonal and horizontal braces are required also to enhance structural stiffness. Wave loads statically analysis gives a credit report on stresses and catastrophic failures.

Keywords Mathematical Modelling, Wave loads, Applications, Jacket Structure, Shallow Water

Nomenclature

F_T = Total force, KN
F_I=Initial force, KN
F_D = Drag force, KN
T = Wave period, s
L = Wave length, m
H = Wave height, m
$\rho = density\ of\ water \frac{kg}{m3}$
ω = Wave frequency, Hz
θ = Incident wave angle
SWL = Still water level

Dp = Pile diameter
Db = Bracing diameter
C_d *= Drag coefficient*
C_m *= Inertia coefficient*
d = water depth
K = Brace factor
A = Area of structure
MI = Inertia moment
MD = Drag moment

Introduction

The reliability, sustainability and performance of offshore jacket structures solely depend upon a good experimental approach to realistically determine the applied forces. Timo (2010) [1] said such structure be designed to experience a little wave loads and movement to provide a stable work for operation such as drilling and production of oil. The water particles in shallow water generally follow an elliptical paths and the relative depth establishes waves to be dispersive or non-dispersive. Progressive failure and fatigue experienced in offshore structures over the years can be traced back to wave loads on the structural members and how these members respond statically or dynamically. This is a great concern to the naval architect because offshore structures often time suffer residual stresses, shears and buckling due to water waves induced vibration. Nallayarasu (2016) [2] reported that the deck structure of a jacket consists of appurtenances such as: walkways, stairways, platforms, equipment supports and monorails as shown in fig. 1. At design stage, the onshore structure is mainly influenced by the loads it carries. While at offshore, is influenced mostly by the environmental loads.

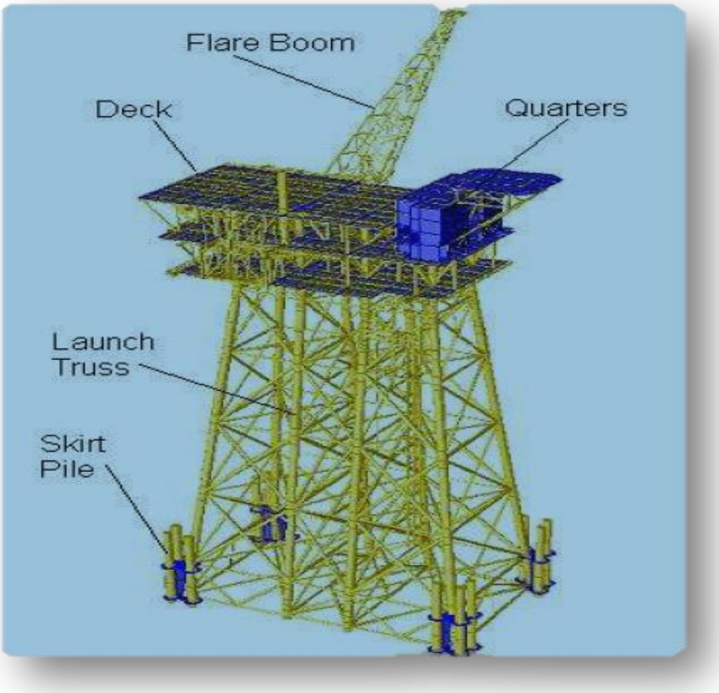

Figure 1: A Jacket Structure [2]

Wave loads are forces experienced by a structure at offshore. They are means of hydrodynamics effecton jacket structures and inducing maximum response. In order to get their dynamic response [3] Saidproper selection of characteristic wave theory is crucial. This is due to the unlikely patterns in the water particle kinematics with regards to still water level (SWL) as well as wavelength ratio. According to them two types of surface waves should be differentiated to suit a certain structure in that zone. These are swells and seas. Swells can be defined as waves that have progressed out of its generating point. It is more regular with long crests and relatively long periods. While seas can be defined as a short period waves created by the winds. Wave loads on offshore structures are the majo rcause for its failure modes [4]. Waves are random, continuing in wave height/length and it reach the offshore structure from several angle concordantly. Mohan *et al*., (2013) [5] studied the static analysis, viscous and potential flow effects to know the wave induced loads on a jacket structures and reported that potential flow has the characteristics of diffraction and radiation around the structure.

Wilson (2003) [6] said that this flow pattern distribution could only be governed by two flow parameters: the Reynold number (*Re*) and Keulegan-Carpenter number (*KC*) and are found for the structural parts and the pattern of flow is estimated and the accurate force coefficients for fluid, drag (C_d) and inertia (C_m) and wave diffraction are chosen accordingly Based on the unsteady form, the sea-condition is usually describe in terms of numerical and statistical wave parameters like significant wave height, spectral period, spectral shape and directionality [7].

2. Method of Coefficient Derivation

While designing the offshore structure, selecting the appropriate values for the coefficients are essential. Chakrabarti (2005) [8] reported that if the kinematics are measured or computed it should be stated clearly and if computed, the theory used. But the kinematics sometimes cannot be directly measured since inertia and drag coefficients assumed time invariant over one cycle of data information. These coefficients can be obtained through:

- Least square technique
- Fourier averaging technique

According to Schoefs and Boukinda, 2004 [9]; Seidel and Kelma (2012)[10] a jacket structure installed offshore, is relatively transparent to wave loading and various type of marine fouling organism may be found on its submerged member which can give efficient means of measuring relative changing after a certain time

Kharade and Kapadiya, (2014) [11] pointed out that the lifetime of a wood structures built offshore is less strong due to marine organisms hence reinforced concrete would better replace timber as the supporting structure for offshore platforms. Determining the exact wave forces, a single design wave for a particular wave theory is applied with a wave height and wave period chosen based on the location of the structure, corresponding pressure field and horizontal components of wave particle velocity and acceleration. Effort to calculate the wind forces and current forces affecting offshore structures have been made in literatures conducted but this present work would develop a mathematical modelling to know the maximum wave forces a jacket structure can carry before it may buckle using linear method to evaluate the integrity of the structure under the wave forces.

3. Material and Methods

Modelling wave loads for shallow water operations subjected to forces and moments caused by wave can play important role in offshore structures at design stage as well as installation. A good calculation of wave loads cannot be overemphasized for economical and reliable design. The methods for calculating wave forces can be divided into different approaches which are determined by the size of the structural member and the height and wavelength of the incident waves. Ratios of these parameters are often used to classify which of the force calculation method is to be adopted. There are the ratios of the structure's diameter to the wavelength (D/L) and wave height to diameter (H/D). The Morison equation is better use when (D/L) < 2 otherwise diffraction theory is used to calculate the wave loads. This present work considered the shallow water in which (D/L) < 1/20.

4. Wave Loads Derivative on a Jacket Structure

Figure 2.is a column subjected to hydrodynamic force and the Morison equation can be modelled in order to determine wave forces since the general form of the equation cannot be applied to all members in the offshore structures. This is because it was developed mainly for a surface piercing cylinder kind of structure.

This work ignored the effect of slamming force which also distorts the kinematic of the wave.

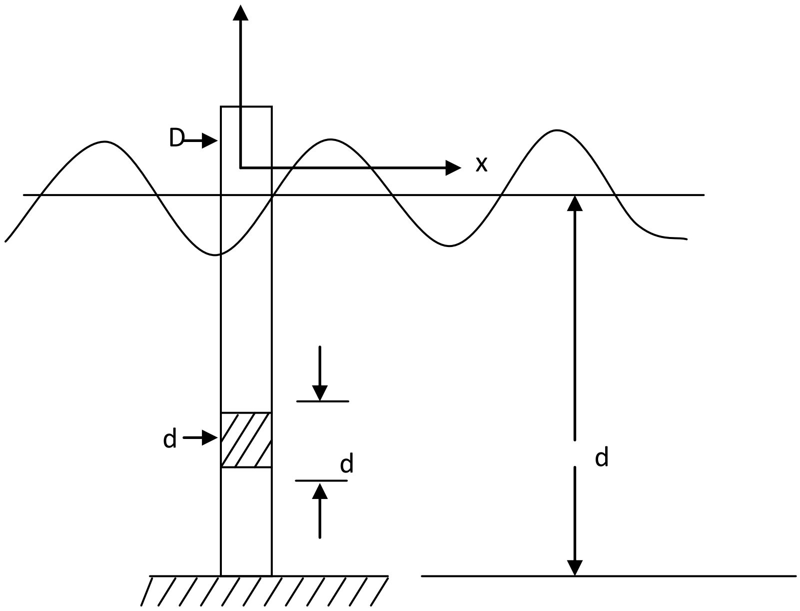

Figure 2: Column Subjected to Hydrodynamic Force

Using the Morison equation, the structure can be integrated from the seabed to the SWL.

$$F_T = C_m \rho \pi r^2 \int_{-d}^{0} \dot{U}_n \mathrm{dz} + C_d \rho_r \int_{-d}^{0} /U_n/U_n \,\mathrm{dz} \qquad (1)$$

The horizontal velocity and acceleration are respectively substituted into 2.1

Horizontal velocity

$$U_n = \frac{HgT}{2L} \frac{Cosh\left[2\pi\left(z+d\right)/L\right]}{\cosh\left(2\pi \, d/L\right)} \cos\theta \qquad (2)$$

Horizontal acceleration,

$$\dot{U}_n = \frac{g\pi H}{L} \frac{Cosh\left[2\pi\left(z+d\right)/L\right]}{\cosh\left(2\pi \, d/L\right)} \sin\theta \qquad (3)$$

The hyperbolic functions are indications that show the approximate exponential decay of the velocity components with increasing distance below the free surface.

Considering the inertia part of (1), we have,

$$F_I = C_m \rho \pi r^2 \int_{-d}^{0} \dot{U}_n \mathrm{dz} \qquad (4)$$

From (3)

$$F_I = C_m \rho \pi r^2 \int_{-d}^{0} \frac{g\pi H}{L} \frac{Cosh\left[2\pi\left(z+d\right)/L\right]}{\cosh \; 2\pi \, d/L} \sin\theta \,\mathrm{dz}$$ But wave number, $k = 2\pi/L$

$$F_I = C_m \rho \pi r^2 \int_{-d}^{0} \frac{g\pi H}{L} \frac{Cosh\left[K\left(z+d\right)\right]}{\cosh \; kd} \sin\theta \mathrm{dz}$$

Let $u = kz + kd$

$$du = kdz \Rightarrow dz = du/k$$

$$F_I = \frac{C_m \rho \pi r^2 \; g \pi H \sin\theta}{L \cosh kd} \int_{-d}^{0} \cosh \; u \; \frac{du}{k}$$

Recall, $u = kz + kd = k\left(z + d\right)$

$$\therefore F_I = \frac{C_m \rho \pi^2 r^2 \; gH \sin\theta}{kL \cos h \; kd} \left[\sinh\left[k\left(z + d\right)\right]\right]_{-d}^{0}$$

$$F_I = \frac{C_m \rho \pi^2 r^2 \ g H \ \sin \theta}{kL \ \cos h \ kd} \sinh kd$$

$$= \frac{C_m \rho \pi^2 r^2 g H \ \sin \theta}{kL} \ \frac{\sinh kd}{\cos h kd}$$

$$F_I = \frac{C_m \rho \pi^2 r^2 \ gH \ \sin \theta \tan h kd}{kL}$$

Also, $\tan h kd = \dfrac{2\pi L}{gT^2}$

$$\Rightarrow L = \frac{gT^2 \tan h(kd)}{2\pi} \quad and \quad k = \frac{2\pi}{L} \text{ hence,}$$

$$F_I = \frac{C_m \rho \pi^2 r^2 \ gH \sin \theta}{\frac{2\pi}{L} . L} \cdot \frac{2\pi L}{gT^2}$$

$$F_I = \frac{C_m \rho \pi^2 r^2 HL \ \sin \ \theta}{T^2}$$

$$F_I = \frac{2\pi \rho r H^2 L}{T^2} \left(\frac{\pi r}{2H} \right) C_m \sin \theta$$

Let, $A_1 = \dfrac{\pi r}{2H}$ so that

$$\therefore F_I = \frac{2 \pi \rho r H^2 L}{T^2} A_1 C_m \sin \theta \tag{5}$$

This is the inertia force the structure experience.
Considering the drag force part on the structure

$$F_d = C_d \rho r \int_{-d}^{0} /U_n/U_n \ d_Z \tag{6}$$

Thehorizontal velocity component is

$$U_n = \frac{HgT}{2L} \ \frac{\cosh [k(z+d)] \cos \theta}{\cosh \ kd}$$

$$/U_n/U_n = \frac{H^2 g^2 T^2}{4L^2}$$

$$\frac{\cos^2 h \ /k(z+d)/\cos \theta/\cos \theta}{\cos^2 h \ kd}$$

$$F_d = \frac{C_d \rho \ r H^2 g^2 \ T^2/\cos \theta/\cos \theta}{4L^2 \cos^2 h \ kd} \int_{-d}^{0} \cos^2 hk(z+d) \text{ dz} \tag{7}$$

From trigonometry we have that

$$Cos^2 \times = \tfrac{1}{2} (1 + \cos \ 2x)$$

$$Cos^2 \ h \ k = \tfrac{1}{2} (1 + \cos h \ 2k)$$

$$\Rightarrow \cos^2 h \ k \ (z+d) = \tfrac{1}{2} [1 + \cos h \ 2k \ (z+d)] \tag{8}$$

Substituting (2.8) into (2.7), expression for drag force yields

$$F_d = \frac{C_d \, \rho \, r \, H^2 \, g^2 \, T^2 / \cos\,\theta / \cos\,\theta}{4L^2 \cos^2 h \;\; kd}$$

$$\int_{-d}^{0} \frac{1}{2} \left[1 + \cos h \, 2k(z+d)\right] dz$$

$$F_d = \frac{C_d \, \rho \, r \, H^2 \, g^2 \, T^2 / \cos\,\theta / \cos\,\theta}{8L^2 \cos\,^2 h \;\; kd}$$

$$\left[z + \frac{\sinh 2k\,(z+d)}{2k} \right]_{-d}^{0}$$

$$F_d = \frac{C_d \, \rho \, r \, H^2 \, g^2 \, T^2 / \cos\,\theta / \cos\,\theta}{8L^2 \cos h^2 \; kd}$$

$$\left[\frac{2kz + \sinh 2k\,(z+d)}{2k} \right]_{-d}^{0}$$

$$F_d = \frac{C_d \, \rho \, r \, H^2 \, g^2 \, T^2 / \cos\,\theta / \cos\,\theta}{16L^2 \, k \cos h^2 \; kd}$$

$$\left[2\,kd + \sinh 2\,kd\right] \tag{9}$$

But, $\tan h\,kd = \dfrac{2\pi L}{gT^2} \Rightarrow \dfrac{\sinh kd}{\cos h\,kd} = \dfrac{2\pi L}{gT^2}$

So that, $\cos h\,kd = \dfrac{gT^2 \sinh kd}{2\pi L}$

$$\cos\,h^2\,kd = \frac{g^2 T^4 \sin\,h^2 kd}{4\pi^2 L^2} \quad and \quad k = \frac{2\pi}{L}$$

(9a)

$$F_d = \frac{C_d \, \rho \, r \, H^2 \, g^2 \, T^2}{16L^2 \, . \, \dfrac{2\pi}{L} \, \dfrac{g^2 \, T^4 \sin\,h^2 \, kd}{4\,\pi^2 \, L^2}}$$

$$/\cos\,\theta / \cos\,\theta \left[\, 2kd \; + \sin h \, 2kd \,\right]$$

$$F_d = \frac{C_d \, \rho \, r \, H^2 \, L \, . \, 2\,\pi}{16 \, T^2 \; \sin\,h^2 \;\; kd} \; /\cos\,\theta / \cos\,\theta$$

$$\left[\, 2kd \; + \sin\,h\,2kd \,\right]$$

$$F_d = \frac{2\,\pi \;\; \rho \, r \, H^2 \, L}{T^2} \qquad \frac{/\cos\,\theta / \cos\,\theta \, . \, Cd}{16 \, \sin\,h^2 \;\; kd} \quad \left[2kd \; + \sin\,h\,2kd\,\right]$$

$$F_d = \frac{2\,\pi \;\; \rho \, r \, H^2 \, L}{T^2} Cd / \cos\,\theta / \cos\,\theta$$

$$\frac{1}{16 \, \sin\,h^2 \;\; kd} \left[\, 2kd \; + \sin h \, 2kd \,\right]$$

Let $A_2 = \dfrac{1}{16 \, \sin\,h^2 \;\; kd} \left[\, 2kd \; + \sin h \, 2kd \,\right]$

$$\therefore F_d = \frac{2\pi\rho r H^2 L}{T^2} A_2 Cd /\cos\theta/\cos\theta \tag{10}$$

The total force acting on the structure is the summation of equations (5) and (10)

$$F_T = \sum_{-d}^{0}(F_i + F_d)$$

$$F_T = \frac{2\pi\rho r H^2 L}{T^2} A_1 C_m \sin\theta$$

$$+ \frac{2\pi\rho r H^2 L}{T^2} A_2 C_d /\cos\theta/\cos\theta$$

$$F_T = \frac{2\pi\rho r H^2 L}{T^2} [A_1 C_m \sin\theta$$

$$+ A_2 C_d /\cos\theta/\cos\theta] \tag{11}$$

Equation (11) is the total force modelled on the structure. This is the point beyond which catastrophic occurs. Having realised the exact force, the various moments on the structure can equally be derived to ascertain realistic stability on structures.

$$M_T = C_m \rho\pi r^2 \int_{-d}^{0} (d+z)\dot{U}_n dz$$

$$+ C_d \rho r \int_{-d}^{0} (d+z) /U_n/ dz$$

$$m_1 = C_m \rho\pi r^2 \int_{-d}^{0} (d+z)\dot{U}_n dz$$

Where mi is the inertia moment

$$m_1 = C_m \rho\pi r^2 \int_{-d}^{0} \dot{U}_n dz = \frac{2\pi\rho r H^2 L d}{T^2}\left(\frac{\pi r}{2H}\right) C_m \sin\theta$$

$$m_1 = \frac{2\pi\rho r H^2 L}{T^2}\left(\frac{\pi r d}{2H}\right) C_m \sin\theta \tag{12}$$

$$m_2 = C_m \rho\pi r^2 \int_{-d}^{0} z\dot{U}_n dz$$

$$= C_m \rho\pi r^2 \int_{-d}^{0} z.\frac{g\pi H}{L}\frac{\cos h[k(z+d)]}{\cos h\, kd}\sin\theta dz$$

$$m_2 = \frac{C_m \rho\pi r^2 g\pi H \sin\theta}{L\cos h kd}\int_{-d}^{0} z\cos h[k(z+d)]dz$$ Applying integration by part equation

$$\int u\,dv = uv - \int v\,du$$

Let $u = z, \quad du = dz$

Let $dv = \cos h[k(z+d)]$

$$V = \frac{\sin h[K(z+d)]}{k}$$

$$m_2 = \frac{C_m \rho\pi r^2 g\pi H \sin\theta}{L\cos h\, kd}$$

$$\left[z\frac{\sin h[k(z+d)]}{k} - \int_{-d}^{0}\frac{\sin h[k(z+d)]dz}{k}\right] m_2 = \frac{C_m \rho\pi r^2 g\pi H \sin\theta}{L\cos h kd}$$

$$\left[z \frac{\sin h\left[k\left(z+d\right)\right]}{k} - \frac{\cos h\left[k\left(z+d\right)\right]}{k^2} \right]_{-d}^{0}$$

$$m_2 = \frac{C_m \ \rho \pi r^2 \ g\pi H \ \sin\theta}{k^2 L \cos h \ kd} \left[1 - \cos h kd\right]$$

Recall that,

$$k = 2\pi / L \Rightarrow k^2 = 4\pi^2 / L^2$$

And $\cos h \ kd = gT^2 \sin h \ kd / 2\pi L$

On substitution, m_2 becomes

$$m_2 = \frac{C_m \ \rho \lambda r^2 \ g\pi H \ \sin \ \theta}{\frac{4\pi^2}{L^2} k . \frac{gT^2 \ \sin h kd}{2\pi L} \cos h kd}$$

$$\left[1 - \cos h (kd)\right]$$

$$m_2 = \frac{C_m \ \rho \ \pi^2 \ r^2 \ HL^2 \ \sin\theta}{2\pi \ T^2 \ \sin \ h \ kd} \left[1 - \cos \ h \ kd\right]$$

$$m_2 = \frac{2\pi \rho r H^2 L^2}{T^2} \ C_m \ \sin\theta$$

$$\left(\frac{r}{4H \sin h kd} \right) \left[1 - \cos h(kd)\right]$$

The inertia force for moment about seabed is given by $M_i = m_1 + m_2$

$$M_i = \frac{2\pi \rho r H^2 L}{T^2} \left(\frac{\pi \ r \ d}{2H} \right) C_m \ \sin \ \theta$$

$$+ \frac{2\pi\rho r H^2 L^2}{T^2} C_m \sin\theta \left(\frac{r}{4H \sin h kd} \right) \left[1 - \cos h(kd)\right]$$

$$M_i = \frac{2\pi r^2 \ \rho H \ L \ d \ C_m \ \sin \ \theta}{T^2}$$

$$+ \frac{2\pi\rho r H^2 L^2}{T^2} C_m \sin\theta \left(\frac{r}{4H \sin h kd} \right) \left[1 - \cos h(kd)\right]$$

Multiply through by 4Hsinhkd and simplify give

$$M_i = \frac{4H \sin h kd . \pi^2 r^2 \ \rho H^2 L d C_m \ \sin\theta}{T^2} + \frac{2\pi\rho r H^2 L^2 \ C_m \ \sin\theta (r) \left[1 - \cos h kd\right]}{T^2 \ 4H \sin h kd}$$

$$M_i = \frac{2\pi \rho r H^2 L^2}{T^2} \left(\frac{2\pi}{L} \ rd \sin h kd \right)$$

$$+ \frac{2\pi\rho r H^2 L^2 r \ C_m \sin\theta \left(1 - \cos h(kd)\right)}{T^2 \ 4H \sin h kd}$$

$$M_i = \frac{2\pi \rho r H^2 L^2}{T^2} \cdot \frac{\pi r}{4H \sin h kd}$$

$$[kd \sin h kd + 1 - \cos h kd] C_m \sin\theta$$

Let $A_3 = \dfrac{\pi r}{4 H \sin h kd} [kd \sin h kd + 1 - \cos h kd]$

Hence, $m_i = \dfrac{2\pi \rho r H^2 L^2}{T^2} A_3 C_m \sin\theta$ (13)

Having obtained expression for the inertia moment, the drag part can easily be integrated using same boundary conditions.

$$M_{di} = cd\rho r \int_{-d}^{0} (d + z) /U_n/U_n d_2 =$$

$$C_d \rho r d \int_{-d}^{0} /U_n/U_n \mathrm{dz} + C_d \rho r \int_{-d}^{0} /U_n/U_n \mathrm{dz}$$

$$M_{di} = cd\rho r \int_{-d}^{0} (d + z) /U_n/U_n \mathrm{dz} = \frac{2\pi \rho r H^2 L C_d d}{T^2}$$

$$\frac{1}{16 \sin h^2 kd} [2kd + \sinh 2kd] /\cos\theta/\cos\theta$$

$$M_{di} = \frac{2\pi \rho r H^2 L^2 C_d /\cos\theta/\cos\theta}{T^2} \frac{1}{16 \sin h^2 kd} \frac{d}{L} [2kd + \sin h 2kd]$$

$$M_{di} = \frac{2\pi \rho r H^2 L^2 C_d}{T^2} /\cos\theta/\cos\theta$$

$$\frac{1}{16 \sin h^2 kd} \left[\frac{2kd^2}{L} + \frac{d \sin h 2kd}{L} \right]$$

$$M_{di} = \frac{2\pi \rho r H^2 L^2 C_d}{T^2} /\cos\theta/\cos\theta$$

$$.\frac{1}{64 \sin h^2 kd} [4 k^2 d^2 + 2kd \sin h 2kd] \quad (14)$$

Similarly,

$$M_{d_{2i}} = C_d \rho r \int_{-d}^{0} z/U_n/U_n \mathrm{dz}$$

$$= C_d \rho r \int_{-d}^{0} 2 \frac{H^2 g^2 T^2}{4L^2} \frac{\cos h^2 [k(z + d)] /\cos\theta/\cos\theta \mathrm{dz}}{\cos h^2 kd}$$

$$M_{d_{2i}} = \frac{C_d \rho r H^2 g^2 T^2 /\cos\theta/\cos\theta}{4L^2 \cos h^2 kd}$$

$$\int_{-d}^{0} z \cos h^2 [k(z + d)] \mathrm{dz}$$

$$M_{d_{2i}} = \frac{C_d \rho r H^2 g^2 T^2 /\cos\theta/\cos\theta}{4L^2 \cos h^2 kd}$$

$$\int_{-d}^{0} z . \frac{1}{2} [1 + \cos 2k (z + d)] \mathrm{dz}$$

$$M_{d_{2i}} = \frac{C_d\ \rho r H^2 g^2 T^2 \quad /\cos\theta/\cos\theta}{8L^2\ \cos h^2\ k\,d}$$

$$\int_{-d}^{0}\left[z + z\cos\ h2k\ (z+d)\right]\mathrm{dz}$$

$$M_{d_{2i}} = \frac{C_d\ \rho r H^2 g^2 T^2 \quad /\cos\theta/\cos\theta}{8L^2\ \cos h^2\ k\,d}$$

$$\left[\int_{-d}^{o} z\,\mathrm{dz} + \int_{-d}^{0} z\ \cos h2k\ (z+d)\right]\mathrm{dz}$$

$$M_{d_{2i}} = \frac{C_d\ \rho r H^2 g^2 T^2 \quad /\cos\theta/\cos\theta}{8L^2\ \cos h^2\ k\,d}$$

$$\left[\frac{z^2}{2} + \frac{Z\ \sin h2k(z+d)}{2k} - \frac{\cos h2k(z+d)}{4k^2}\right]_{-d\,2}^{0}$$

$$M_{d_{2i}} = \frac{C_d\ \rho r H^2 g^2 T^2 \quad /\cos\theta/\cos\theta}{8L^2\ \cos h^2\ k\,d} \quad \left[\frac{1}{4k^2} - \frac{\cos\ h2kd}{k^2} - \frac{d^2}{2}\right]$$

$$M_{d_{2i}} = \frac{C_d\ \rho r H^2 g^2 T^2 \quad /\cos\theta/\cos\theta}{8L^2\ \cos h^2\ k\,d}$$

$$\frac{1}{4}\left[\frac{1}{4k^2} - \frac{\cos\ h2kd}{k^2} - 2d^2\right]$$

But, $\cos h^2kd = \dfrac{g^2T^4\ \sin h^2kd}{4\pi^2 L^2}$

$$M_{d_{2i}} = \frac{C_d\ \rho r H^2 g^2 T^2 \quad /\cos\theta/\cos\theta}{8L^2\ \dfrac{g^2T^4 \sin\ h^2\ k\,d}{4\pi^2 L^2}}$$

$$\frac{1}{4}\left[\frac{1}{k^2} - \frac{\cos\ h_2\ kd}{k^2} - 2d^2\right]$$

$$M_{d_{2i}} = \frac{C_d\ \rho \pi^2 H^2 \quad /\cos\theta/\cos\theta}{8T^2 \sin h^2\ kd}$$

$$\frac{1}{k^2}\left[1 - \frac{\cos\ h_2\ kd}{k^2} - 2k^2d^2\right]$$

$$M_{d_{2i}} = \frac{C_d\ \rho r H^2 L^2 \quad /\cos\theta/\cos\theta}{32T^2\ \sin h^2\ kd}$$

$$\left[1 - \cos\ h^2\ kd\ -2k^2d^2\right]$$

$$M_{d_{2i}} = \frac{2\rho r H^2 L^2 Cd_1}{T^2}\ \frac{1}{64\sin h^2 kd}$$

$$\left[1 - \cos h^2\ kd - 2k^2d^2\right]\ /\cos\theta/\ \cos\theta \qquad (15)$$

Adding equations (14) and (15)

$$M_d = \frac{2\pi \rho r H^2 L^2 \quad Cd/\cos\theta/\cos\theta}{T^2}$$

$$\frac{1}{64 \sin h^2 kd}\left[4k^2 \ d^2 + 2kd \sin \ h2kd\right] +$$

$$\frac{2\pi \rho r H^2 L^2 \quad Cd/\cos\theta/\cos\theta}{T^2}$$

$$\frac{1}{64 \sin h^2 \ kd}\left[1 - \cos h2kd - 2k^2 \ d^2\right]$$

$$M_d = \frac{2\pi \rho r H^2 L^2 \quad Cd/\cos\theta/\cos\theta}{T^2} \ .$$

$$\frac{1}{64 \sin h^2 \ kd}\left[4k^2 \ d^2 + 2kd \sinh 2kd + 1 - \cos h2kd \ - 2k^2 \ d^2\right]$$

$$M_d = \frac{2\pi \rho r H^2 L^2 \quad Cd/\cos\theta/\cos\theta}{T^2}$$

$$\frac{1}{64 \sin h^2 kd}\left[2k^2 \ d^2 + 2kd \sin h2kd + 1 - \cos h2kd\right]$$

Let $A_4 = \frac{1}{64 \sin h^2 \ kd}\left[2k^2 \ d^2 + 2kd \sin h(2kd) \ \right] + 1 - \cos h2kd$

$$\therefore M_d = \frac{2\pi \rho r H^2 L^2 \quad Cd \ \ A_4/\cos\theta/\cos\theta}{T^2}$$

Total moment about the seabed on the structure is

$$M_T = \sum_{-d}^{0}(m_i + m_d);$$

Where, $-d$ and 0 are boundary conditions

$$M_T = \frac{2\pi \rho r H^2 L^2}{T^2} \quad A_3 C_m \sin\theta$$

$$+ \frac{2\pi \ \rho r H^2 L^2 \ Cd \ \ A_4/\cos\theta/\cos\theta}{T^2}$$

$$M_T = \frac{2\pi \rho r H^2 L^2}{T^2}$$

$$\left[A_3 C_m \sin\theta \ + A_4 Cd/\cos \ \theta/\cos \ \theta\right] \qquad (16)$$

The two equations, (11) and (15) confirm the modelling of wave loads on offshore jacket. Figure 3 is a flowchart used to write computer program in MATLAB language for obtaining wave forces and the moments on the jacket

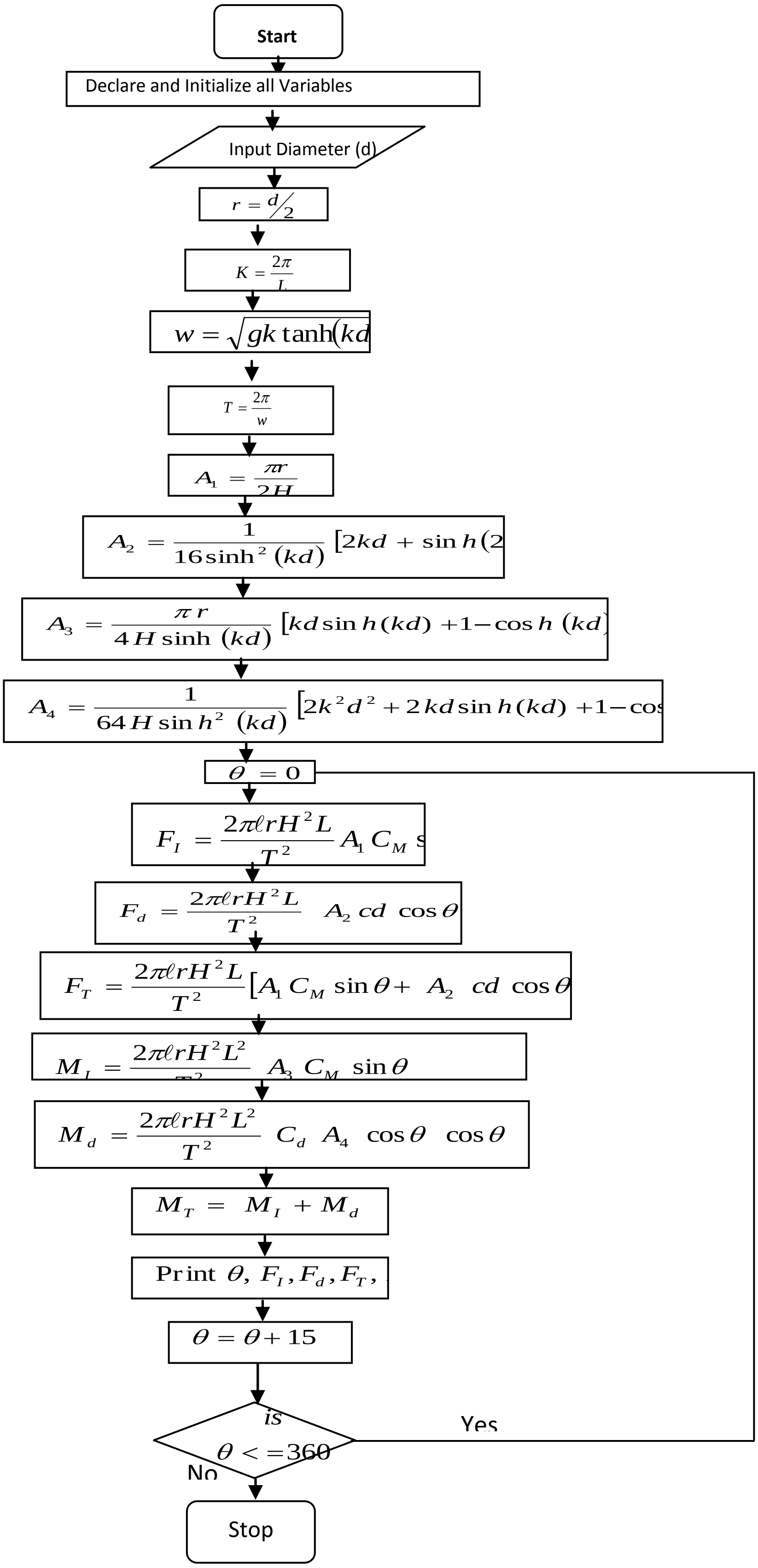

Figure 3: Flowchart Used for Obtaining Forces and Moments on Jacket

5. Results and Discussions

An important application of offshore jacket structure for shallow water operations is characterised by forces induced on the jacket structure and how this response is a function of the maximum loading. To effectively analyse the resulting solution, a mathematical enunciation employed model the internal forces affecting the jacket. The waves are stochastic though. For wave forces on a pile, the maximum velocities do occur at high portion of the water column. Inertia force for small amplitude occurs at still water level, appears only in the idealized oscillatory flow. Hence in shallow water the drag force predominates over the inertia force. It is this inertia force and drag force that enables us to get the total force acting on the structure.

Fig. 4a and 4b show that at 0 degree the inertia force on the structure is 0kN. That is significant wave effect. As the wave increases, inertia force increases to 1500kN. It then implies that the increase in wave causes a corresponding increase in the loads on the jacket and vice versa. The average force is estimated to be 146.15kN after which buckling may occur. This is because the vertical structural load is static load, while the lateral wave loading fluctuates and are affected by the incident wave angle in that the structure in waves form orbits and neglect the tangential component A typical vertical moment of the wave behaviour on a structure is shown in figure 6. Linear wave incident on the structure induced bending effect due to the wave of translation and structure could no longer regain its stability. The stress induced is capable of causing buckling.

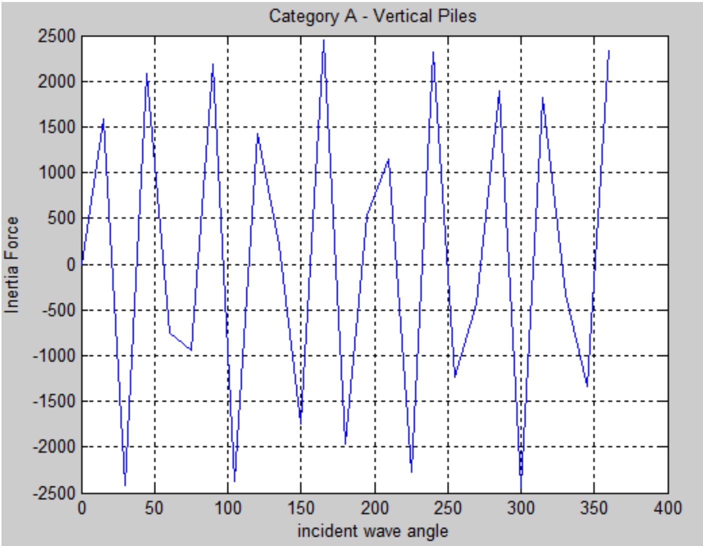

Figure 4a: Inertia Force against Incident Wave Angle

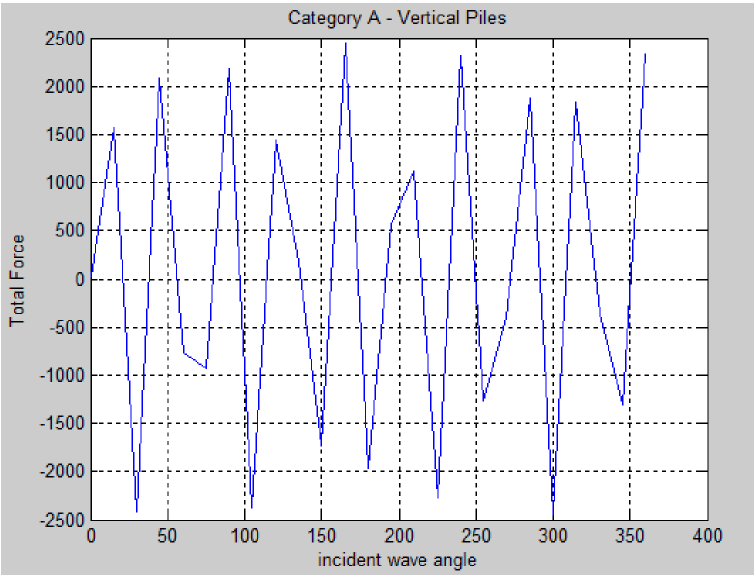

Figure 4b: Total Force against Incident Wave

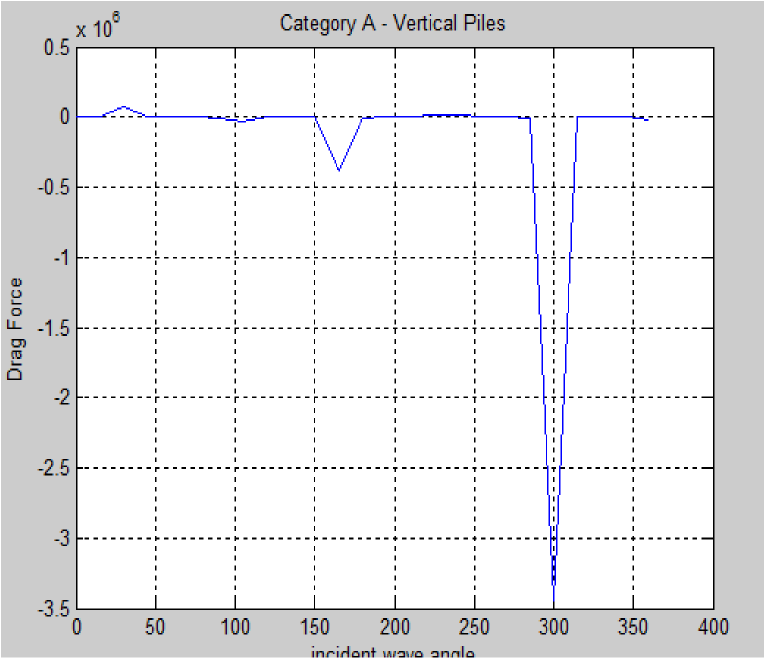

Figure 5: Drag Moment against Wave Angle

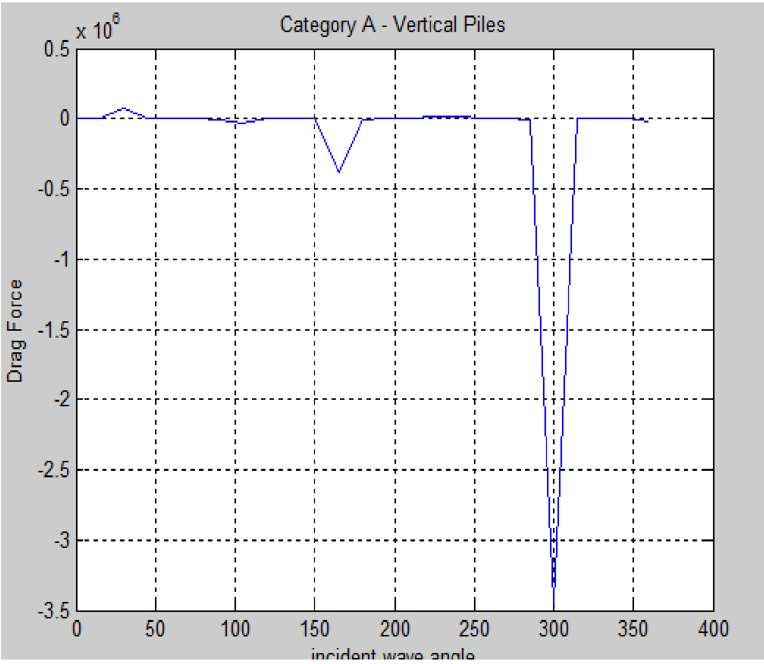

Figure 6: Drag Moment against Wave Angle

6. Conclusion and Recommendation

Modelling wave loads on a structure is a very crucial and dynamic task. The amount of defect meted to a jacket structure is a function of the environmental conditions. This work calculated forces on the various members of the jacket and ensures that a jacket structure have to withstand reasonable amount of forces throughout its life time. The moment acting on the jacket for different wave incident revealed that, by choosing the maximum moment creating load enhance the stability of the structure. Wave loads derivative that characterised forces on the vertical piles and inclined member of the structures are computed using MATLAB programming language. The incident wave angle was taken from 00 to 3600 to make a period at 150 intervals. The mathematical modelling derived was critically applied to ascertain the integrity of offshore jacket maintaining the linear approach. At least two special cases were taken in to consideration for the modelling: the vertical member and the inclined member of a jacket structure to ensure repeatability within the estimated average percentage

Also, marine growths and fouling increases failure rapidly on a fixed jacket facilitating a progressive failure in the structural response in the shallow water. Furthermore, it was observed that the vertical stress is proportional to the depth of the water. The focus has been on how the effect can be determined and modelled in operations and applications. The mathematical modelling derived is critically applied to ascertain the integrity of offshore jacket maintaining the linear approach, and found useful.

7. Recommendations

Wave loads on offshore structures are inherent and are among the most severe hazard that it suffers. Sea information as well as data collection/collation and type of operation should base on interest. Based on the investigation carried out, the followings recommendations are reached:

- The operational point of structure should be defined with respect to the environmental conditions
- The jacket should not experience more than 146.15kN to avoid buckling
- A difference in wave loads calculated based on a linear method should be made less conservative
- The nominal stress due to forces, and moments should be studied

The relationship between sea state and structure should be developed

Acknowledgement

We express our profuse thankful heart to the immense contribution of Dr. I.E Douglas whose assistance fillips this work to a great extent; and to Dr. Christian S. Yorgure, and Nne Saturday for their assistances.

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APPENDIX A:

Resultant Forces and Moments

θ (theta)	Fi (KN)	Fd (KN)	Ft(KN)	Mi(KN/m)	Md(KN/m)	Mt(KN/m)
0	1.0e+03 * 0	1.0e+06 *0.0017	1.0e+03 *0.0278	1.0e+07 * 0	1.0e+03 *3.2295	1.0e+07 *0.0000
15	1.0e+03 *1.5914	1.0e+06 *-0.0029	1.0e+03 *1.5754	1.0e+07 * 4.2493	1.0e+03 *-1.8639	1.0e+07 *4.2493
30	1.0e+03 *-2.418	1.0e+06 *0.0708	1.0e+03 *-2.4173	1.0e+07 * -6.4562	1.0e+03 *0.0768	1.0e+07 *-6.4562
45	1.0e+03 *2.0824	1.0e+06 *0.0061	1.0e+03 *2.09	1.0e+07 * 5.5602	1.0e+03 *0.8912	1.0e+07 *5.5602
60	1.0e+03 *-0.7459	1.0e+06 *-0.0019	1.0e+03 *-0.7712	1.0e+07 * -1.9918	1.0e+03 *-2.9295	1.0e+07 *-1.9918
75	1.0e+03 *-0.949	1.0e+06 *0.002	1.0e+03 *-0.9254	1.0e+07 * -2.5339	1.0e+03 *2.7439	1.0e+07 *-2.5339
90	1.0e+03 *2.1878	1.0e+06 *-0.0084	1.0e+03 *2.1822	1.0e+07 * 5.8418	1.0e+03 *-0.6484	1.0e+07 *5.8418
105	1.0e+03 *-2.3751	1.0e+06 *-0.029	1.0e+03 *-2.3767	1.0e+07 * -6.3419	1.0e+03 *-0.1875	1.0e+07 *-6.3419
120	1.0e+03 *1.4209	1.0e+06 *0.0025	1.0e+03 *1.4393	1.0e+07 * 3.794	1.0e+03 *2.1408	1.0e+07 *3.794
135	1.0e+03 *0.2163	1.0e+06 *-0.0017	1.0e+03 *0.1887	1.0e+07 * 0.5774	1.0e+03 *-3.2043	1.0e+07 *0.5774
150	1.0e+03 *-1.7495	1.0e+06 *0.0034	1.0e+03 *-1.7359	1.0e+07 * -4.6713	1.0e+03 *1.5791	1.0e+07 *-4.6713
165	1.0e+03 *2.4419	1.0e+06 *-0.3829	1.0e+03 *2.4417	1.0e+07 * 6.5201	1.0e+03 *-0.0142	1.0e+07 *6.5201
180	1.0e+03 *-1.9606	1.0e+06 *-0.0047	1.0e+03 *-1.9706	1.0e+07 * -5.2351	1.0e+03 *-1.1567	1.0e+07 *-5.2351
195	1.0e+03 *0.5371	1.0e+06 *0.0018	1.0e+03 *0.5635	1.0e+07 * 1.434	1.0e+03 *3.074	1.0e+07 *1.434
210	1.0e+03 *1.1446	1.0e+06 *-0.0022	1.0e+03 *1.1229	1.0e+07 * 3.0563	1.0e+03 *-2.523	1.0e+07 *3.0563
225	1.0e+03 *-2.2762	1.0e+06 *0.0125	1.0e+03 *-2.2724	1.0e+07 * -6.0777	1.0e+03 *0.4357	1.0e+07 *-6.0777
240	1.0e+03 *2.3137	1.0e+06 *0.0159	1.0e+03 *2.3167	1.0e+07 * 6.178	1.0e+03 *0.3428	1.0e+07 *6.178
255	1.0e+03 *-1.2393	1.0e+06 *-0.0023	1.0e+03 *-1.2599	1.0e+07 * -3.309	1.0e+03 *-2.4014	1.0e+07 *-3.309
270	1.0e+03 *-0.4308	1.0e+06 *0.0017	1.0e+03 *-0.4039	1.0e+07 * -1.1504	1.0e+03 *3.1295	1.0e+07 *-1.1504
285	1.0e+03 *1.8939	1.0e+06 *-0.0042	1.0e+03 *1.8827	1.0e+07 * 5.0568	1.0e+03 *-1.2954	1.0e+07 *5.0568
300	1.0e+03 *-2.4466	1.0e+06 *-3.4512	1.0e+03 *-2.4467	1.0e+07 * -6.5329	1.0e+03 *-0.0016	1.0e+07 *-6.5329
315	1.0e+03 *1.8235	1.0e+06 *0.0038	1.0e+03 *1.8359	1.0e+07 * 4.869	1.0e+03 *1.4364	1.0e+07 *4.869
330	1.0e+03 *-0.324	1.0e+06 *-0.0017	1.0e+03 *-0.3513	1.0e+07 * -0.865	1.0e+03 *-3.1729	1.0e+07 *-0.865
345	1.0e+03 *-1.3313	1.0e+06 *0.0024	1.0e+03 *-1.3117	1.0e+07 * -3.5547	1.0e+03 *2.2738	1.0e+07 *-3.5547
360	1.0e+03 *2.3467	1.0e+06 *-0.0209	1.0e+03 *2.3445	1.0e+07 * 6.266	1.0e+03 *-0.2599	1.0e+07 *6.266